SCUFFING BEHAVIOR OF SINGLE-CRYSTAL ZIRCONIA CERAMIC MATERIALS

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INTRODUCTION

Scuffing, described as sudden catastrophic failure of lubricated sliding surfaces, is usually characterized by a sudden rapid increase in friction, temperature, and noise, and is an important failure mode on sliding surfaces [1]. In metallic materials, scuffing results in severe plastic deformation of surfaces in contact. Structural ceramic materials are currently being used in some tribological systems to address scuffing problems in lubricated components. For example, zirconia (ZrO_2) ceramic plungers have been successfully used in fuel injector systems for heavy duty diesel engines, primarily to address scuffing failures in low-lubricity diesel fuels. Given the fact that scuffing, at least in metals, involves severe plastic deformation, and that ceramic materials in general do not plastically deform as easily as metals, it is reasonable to assume that ceramics are less susceptible to scuffing. However, some ceramic materials are capable of plastic deformation, and other material mechanisms may be involved in scuffing failure. For effective use of ceramic materials to address scuffing problems, it would be very instructive to assess if scuffing can occur in this class of material and by what mechanisms.

EXPERIMENTAL

In the present study, two variants of Y_2O_3-stabilized ZrO_2 alloys were evaluated: cubic ZrO_2-9%Y_2O_3 and tetragonal ZrO_2-3%Y_2O_3 single crystals. Scuffing tests were conducted with a block-on-ring contact configuration using ZrO_2 as the block and AISI 4620 alloy steel as the ring. Tests were conducted at constant ring speeds of 500-1750 rpm. The step-load increase protocol started at a load of 25 N, with an increase of 25 N /min until scuffing occurred. The normal load, tangential and lateral forces, rotation speed, and number of cycles were monitored continuously during the test. The friction coefficient was calculated as the ratio of tangential and normal forces. Multiple repeat tests were conducted for each material. An unformulated synthetic polyalphaolefin (PAO-4) was used as lubricant.

Extensive post-scuffing test analyses were conducted on the ZrO_2 material. The surface damage modes were assessed by scanning electron microscopy (SEM). X-ray diffraction was conducted in contact and non-contact areas of the tetragonal material to determine the crystal structure of the material in and outside the contact areas after tribological testing.

RESULTS

The cubic material showed a sudden catastrophic failure characteristic of scuffing (figure 1). The mechanism of failure was, however, by fracture instead of severe plastic deformation typical for metallic materials, with extensive cracking oriented perpendicular to the sliding direction. In the tetragonal material, there was no sudden catastrophic failure in spite of much higher contact severity during testing with the material. Initial friction coefficient was high, about 0.2, but decreased gradual to a near steady value in the range of 0.05 to 0.07. This resilience of the tetragonal material is the result of the sequential operation of several frictional stress dissipation mechanisms of plastic deformation: Ferroelastic domain switching occurred at low loads, then tetragonal-to-monoclinic phase transformation, and finally deformation by slip at elevated temperatures towards the end of the test [2,3]. Based on the results of the present study, materials with multiple sequential dissipation mechanisms are expected to exhibit higher scuffing resistance.

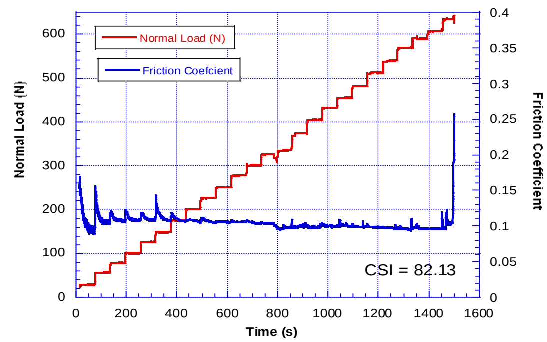

Figure1: Evolution of normal load and Friction coefficient during scuffing test at 750 rpm for cubic zirconia.

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